EVALUATING RESEARCH ON NATURAL RESOURCE MANAGEMENT: THE CASE OF SOIL FERTILITY MANAGEMENT IN KENYA

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A fundamental challenge facing Kenya's agricultural research establishment is how to demonstrate that new initiatives in research on soil fertility management can contribute to national growth and equity objectives. A simplified method for quantifying the value of research in soil fertility management has been developed through a recent collaborative effort between ISNAR and the Kenya Agricultural Research Institute (KARI). This method estimates the possible economic benefits that could ultimately result from research-induced increases in commodity yields.

A modeling exercise was carried out, focusing on the potential impact on commodity yields of the research activities of KARI's Soil Fertility and Plant Nutrition Research Programme. Some of the factors considered include the distribution of commodities over different production systems, and the distribution of these systems over different geographical zones. The results reveal that different farm-level interventions have the potential to make a significant impact in different zones and across research themes that are important to farmers. The combined estimated gains could add over 60 billion Kenyan shillings (almost 1 billion U.S. dollars) in economic value to Kenya's rural sector over 30 years.

These results suggest that efforts to integrate applied commodity-focused research with farming-systems-oriented adaptive research initiatives are important. They also indicate that, while high rainfall areas will experience the largest gains on aggregate, significant benefits also accrue to Kenya's arid and semi-arid areas.

The method remains unsatisfactory for several reasons. Due to certain limits on data and resources, the procedure could not allow for variations due to differences in estimated net yield gains. Differences in impact were instead attributed to variations in the quantities of specific commodities produced per zone. Potential benefits that are unrelated to commodity yields are also ignored.

Issues

Natural resource degradation is widely recognized as a major contributor to sluggish growth in African agriculture. Throughout Kenya, the specter of soil nutrient depletion looms large. With increasing land pressure from a burgeoning population, nutrient losses (e.g., from leaching and erosion) and crop removals often exceed additions from biological processes (e.g., nitrogen fixation) and applications of organic and inorganic fertilizers. Yields of key commodities have stagnated, not only in areas with marginal agricultural potential, but also in those with relatively good production prospects.

Kenya's agricultural research establishment has responded vigorously to this challenge. For instance, Kenya's major national research organization, the Kenya Agricultural Research Institute (KARI), allocates 40% of funds from the European Union to research on soil fertility replenishment. However, the potential economic impact of this relatively new area of research is unclear; the potential returns to alternative research themes and the likely distribution of any gains across the country are still unknown. This information is crucial to managers in agricultural research institutions as they prioritize research thrusts and allocate resources. It is also important to national policy makers weighing investment in agriculture against investment in other economic sectors, and investment in agricultural research against other segments of the agricultural sector.

While Kenya's national policy makers are becoming increasingly concerned about the effect of extant agricultural practices on soil fertility, they have long been preoccupied with agriculture's contribution to national growth (or efficiency) and equity. Apprehensions about soil fertility replenishment and the long term sustainability of agricultural systems appear to be tempered by more immediate concerns for income expansion and distribution. Hence, a fundamental challenge facing Kenya's agricultural research establishment is how to demonstrate that new initiatives in soil fertility management research can contribute to national growth and equity objectives.

While pressures to quantify the potential impact of research in soil fertility management have been growing, a theoretically-consistent and analytically-tractable method to meet this challenge has been lacking. ISNAR has, in recent years, contributed to bridging this gap through collaboration with KARI's Soil Fertility and Plant Nutrition Research Programme (SFPNRP). During this collaboration, an intentionally simplified *ex ante* approach to evaluating research on natural resource management (NRM) was developed, and it was found to add considerable insight regarding the likely distribution of research benefits across themes and across geographical target zones. Below, the modeling strategy employed in this approach is described, the major results are summarized, and their implications for research management and policy are discussed.

Modeling Strategy

The processes that drive the decline and replenishment of soil fertility are apparent over spatial and temporal scales that extend well beyond those covered by most agricultural production processes. A complete evaluation of soil fertility management research interventions would therefore integrate theoretical perspectives from a number of biophysical and socioeconomic disciplines, using data generated at several levels of aggregation. But every modeling exercise must resolve the ever-present tension between rigor and tractability. Invariably, the balance depends on how the modeling challenge is framed, and on the amount and quality of information available to analysts. An exercise was conducted by the SFPNRP's priority-setting working group, which included not only Programme scientists, but also Ministry of Agriculture extension officers, and research-extension liaison officers from four different

districts. This helped orient discussions toward farm-level problems and constraints. At the conclusion of the exercise, a one-day workshop was held during which the priorities that emerged from the assessment were discussed, validated, and adopted by a range of stakeholders. Farmers and farmers' representatives were also involved more directly in the workshop. The exercise began in early 1997 and ended in early 1998.

Early on, the working group determined that a focus on the impact of the SFPNRP's research activities on agricultural commodity yields was justifiable, for two reasons: soil-fertility management technologies developed by the program are embedded within agricultural management practices, and commodity yield increases—or production cost reductions—are fundamental to determining the adoption rates for these

technologies. This simplifying assumption was important for it raised the possibility of taking relatively well-understood methods for *ex ante* evaluation of commodity research initiatives, and adapting them for use in NRM research evaluation. These methods, which have been used widely by ISNAR and other organizations, rely on estimates of changes in aggregate measures of social welfare (i.e., economic surplus) arising from shifts in aggregate supply that, in turn, result from research- induced increases in commodity yields at the farm level.

Soil fertility management research is typical of other NRM or factor-based research in that it relies for its impact on the interplay of intricate biophysical effects in complex farming systems featuring several commodities. Quantifying the economic impact of research on soil fertility management through changes in economic surplus calls for techniques that simultaneously keep track of farm-level yield gains and aggregate supply shifts for a number of commodities. The modeling challenges faced by the working group were: identifying and quantifying multicommodity net yield gains at the farm level under different soil fertility management research interventions, aggregating these farm-level gains to regional and national supply shifts for affected commodities, and translating these supply shifts into changes in economic surplus.

A long history of soils research at KARI, and reasonably good, albeit scattered, information on various aspects of Kenya's agricultural sector allowed these steps to be completed with a considerable degree of rigor. Various types of information were included: spatially-disaggregated agroclimatic data; time series on the regional and aggregate yields, output levels, and prices of the major commodities produced in most parts of Kenya; background information on farmer constraints, technology adoption, and socioeconomic differentiation; and data on key variables describing the soil resource base (nutrient balances, toxicity, and depth). Using these data, the group identified research target zones, specified themes, estimated zone-specific potentials for technology generation and adoption, estimated their associated farm-level yield gains under each theme, and computed aggregate economic benefits based on multicommodity supply shifts.

Research Target Zones

Like many NRM research interventions, technologies that improve soil fertility management are highly location-specific. To determine the potential impact of innovations developed by the SFPNRP, the group had to take the spatial heterogeneity of soil into account. The cost and effort of fully capturing Kenya's immense geographic diversity in soil features could have easily overwhelmed the evaluation exercise, but geographic information systems (GIS) applications proved extremely useful in circumventing this potential problem—in an unexpected way.

During *ex ante* impact assessment of KARI's commodity research programs, GIS applications demonstrated the importance of previously-under- appreciated spatial diversity in assessing the impact of commodity research. But for the SFPNRP, the same applications proved the opposite point. Using total annual precipitation, elevation, and population density as zoning criteria, the working group identified large spatial units that encompassed numerous soil types, types within which soil fertility management technologies should have relatively homogeneous biophysical effects on production.

Following several mapping iterations, five research target zones were identified: zone I covers Kenya's low-altitude and relatively high-rainfall coastal zone; zone II is comprised of arid and semi-arid lands with a relatively low population density; zone III encompasses arid and semi-arid areas with a comparatively high population density (i.e., the so-called "hilly masses" that are small in area but important for human settlement); zone IV consists of mid-altitude, medium-rainfall areas with a high population density; and zone V represents high-altitude areas with very high rainfall and both high and low population densities.

Research Themes

Using a range of quantitative and qualitative data collected during numerous farmer-characterization surveys, the working group completed a detailed, zone-specific constraint identification and analysis.

Research activities that addressed key farmer constraints were then identified. Activities that addressed similar constraints were grouped into four themes: problem soils management (PSM), inorganic

fertilizer management (IFM), soil organic matter management (SOMM), and technology transfer (TT).

The working group fully recognized that success in addressing, for example, soil acidity as part of problem soils management, would improve prospects for better inorganic and organic fertilizer management under the themes of "inorganic fertilizer management" and "soil organic matter management." Similarly, increasing the organic matter content of soil would probably reduce hard-setting, crusting, and leaching, which in turn would increase the impact of improved inorganic fertilizer management. Such interactions across research interventions were seen as fundamental to soil fertility management—or to any NRM technology, for that matter—and were explicitly taken into account throughout the exercise. The recent emphasis on "integrated nutrient management" at KARI and elsewhere in the Kenyan agricultural research system also reflects this concern. However, the working group determined that, to the extent that research overrides particular farm-level constraints, grouping research activities based on the similar sets of constraints they addressed was both justifiable and sensible for this activity. The alternative—lumping research activities together under a broad "integrated nutrient management" theme—would have been counter-productive.

Farm-Level Impact

The working group provided estimates of multicommodity yield gains from technologies that were generated under each theme and subsequently adopted by farmers. First, the principal production (or farming) systems in the target zones were described and the percentage of farmed area they used was estimated. Within each production system, the percentage of farmed land devoted to particular commodities was also specified. Table 1 shows the results for zone IV.

Second, the "raw" minimum, most likely, and maximum net yield gains were estimated for all affected commodities and production systems. This was done for each theme and zone by combining estimates of minimum, most likely, and maximum *gross* yield gains with assessments of the costs incurred in attaining those gains. Table 2 shows the results for soil organic matter management in zone IV.

Table 1. Production Systems in Zone IV

Production System (PS)	Share of Production System in Target Zone (%)	Commodities (and % of shares) in Each Production System
PS-1	30	Maize (45), beans (15), tea (10), bananas (8), dairy (7), horticulture (5), cassava (5), millet (5)
PS-2	20	Coffee (50), maize (20), dairy (15), beans (8), bananas (5), Irish potato (2)
PS-3	15	Tea (60), Irish potato (15), dairy (10), horticulture (10), maize (5)
PS-4	10	Sugarcane (45), maize (30), dairy (8), beans (8), bananas (4), groundnut (3) soybean (2)
PS-5	8	Sorghum (25), cassava (20), maize (15), livestock (11), millet (8), beans (8), sweet potato (5), groundnut (4), sunflower (2), horticulture (2)
PS-6	7	Horticulture (50), dairy (20), Irish potato (20), flowers (10)
PS-7	7	Dairy (80), horticulture (20)
PS-8	2	Coffee (90), flowers (10)
PS-9	1	Sugarcane (100)

Third, these estimated "raw" net yield gains were adjusted according to the share of every affected commodity within each affected production system (table 2, column 3) and the importance of these production systems in the specified target zones (table 1, column 2). Table 2 shows the results of one such adjustment in zone IV, where investment in soil organic matter management research was judged to have a potential impact on only three of the zone's major production systems. Within the affected systems, estimated potential benefits varied considerably across commodities.

Table 2. "Raw" and "Adjusted" Net Yield Gains for "Soil Organic Matter Management" in Zone IV

Prod. System	Commodity	Share in System	"Raw" Net Yield Gains (%)			"Adjusted" Net Yield Gains (%)		
			Min.	Most Likely	Max.	Min.	Most Likely	Max.
PS-1	Maize	45%	17	46	68	2.30	6.21	9.18
	Beans	15%	12	25	123	0.54	1.13	5.54
	Tea	10%	9	18	27	0.27	0.54	0.81
	Bananas	8%	6	12	38	0.14	0.29	0.91
	Cabbage/ Kale	5%	29	48	63	0.44	0.72	0.95
	Finger Millet	5%	5	9	18	0.08	0.14	0.27
PS-2	Coffee	50%	105	140	175	10.50	14.00	17.50
	Maize	20%	17	46	68	0.68	1.84	2.72
	Potatoes	2%	7	23	54	0.03	0.09	0.22
	Bananas	5%	6	12	37	0.06	0.12	0.37
	Beans	8%	12	25	123	0.19	0.40	1.97
PS-7	Cabbage/ Kale	20%	29	48	63	0.41	0.67	0.88

Aggregation Procedures

The "adjusted" net yield gains were used to model outward shifts in the aggregate supply of the relevant commodities. Associated changes in economic surplus were then computed, using predetermined figures for farmers' minimum acceptable (threshold) net yield gains, aggregate commodity output and price levels, and adoption profiles for the technologies developed under each theme.

Assumptions about the structure of commodity markets strongly influence the magnitude and distribution of economic surplus generated by supply shifts. Ideally, market conditions for all the commodities affected by the themes would have been specified for each zone, zone-specific potentials for technology generation and adoption would have been used to compute zonal supply shifts, and the national supply shift for each commodity would have been computed as the sum of these zonal shifts. However, information on regional market conditions was not available for the range of commodities under analysis. Moreover, the large number of commodities (35) whose yields might be affected by the four themes rendered impractical a regional disaggregation of commodity markets, given the limited time and financial resources. "National" markets with "national" prices and no internal transaction costs were therefore assumed for all commodities. The given themes were also assumed to have affected all commodities uniformly across zones (table 3).

This procedure did not allow for variations in research impact across zones due to differences in estimated net yield gains, and all such variations were instead attributed to differences in the quantities of affected commodities produced in each zone. In this way, it was analogous to a simplistic congruence methodology and was rather unsatisfactory. However, the results of this crude approach were reasonable. Technologies generated as part of "soil organic matter

management" and "technology transfer" were determined to have higher probabilities of exceeding dissemination thresholds, and somewhat higher conditional net yield gains than those developed under the other themes. These estimates, along with the assumed adoption profiles and the spatial configuration of agriculture, determined the returns to research investment for each theme and zone.

Table 3. Potential for Technology Generation across All Themes and Zones

	Estimated Net Yield Gains (%)			Estimated Dissemination Threshold	Probability of Exceeding Threshold	Conditional Net Yield Gains (%)
Theme	**Minimum**	**Most Likely**	**Maximum**			
PSM	3.11	6.88	11.91	10.00	0.08	10.56
IFM	3.90	8.34	14.03	10.00	0.11	10.59
SOMM	4.34	7.76	13.18	10.00	0.28	11.18
TT	3.85	7.67	12.00	8.00	0.21	10.93

Research Benefits

The estimated economic benefits of SFPNRP's research activities equaled 63 billion Kenya shillings over 30 years, or roughly 2,100 shillings per capita. (At the time this study was conducted, 1 U.S. dollar was equivalent to 63 Kenya shillings). In comparison, returns to KARI's research on sorghum, cassava, wheat, and maize were estimated at 2.4, 12, 17, and 89 billion shillings, respectively.

Research aimed at improving inorganic fertilizer management and improving soil organic matter management would add over 55 billion shillings (87% of total gains) in economic value to Kenya's rural sector. Innovations that overcome problematic soils and improve the adoption of existing technologies would improve social welfare by about 8 billion shillings (figure 1 shows the distribution of estimated gains). This may
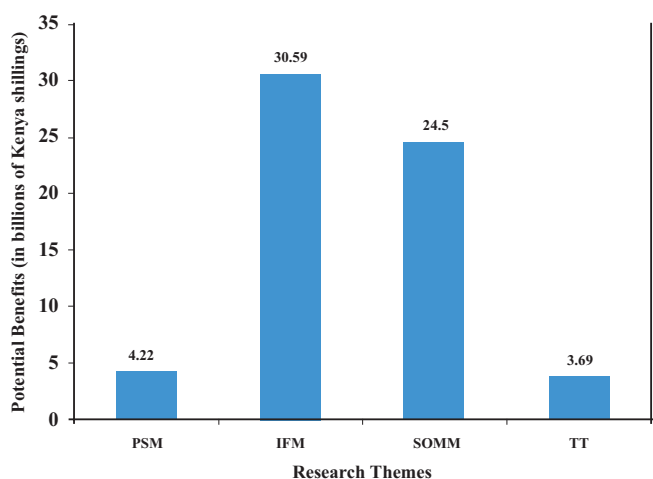
PSM: Problem soils management

IFM: Ingoranic fertilizer management

SOMM: Soil organic matter management

TT: Technology transfer

Figure 1. Potential Benefits to SFPNRP Research Themes
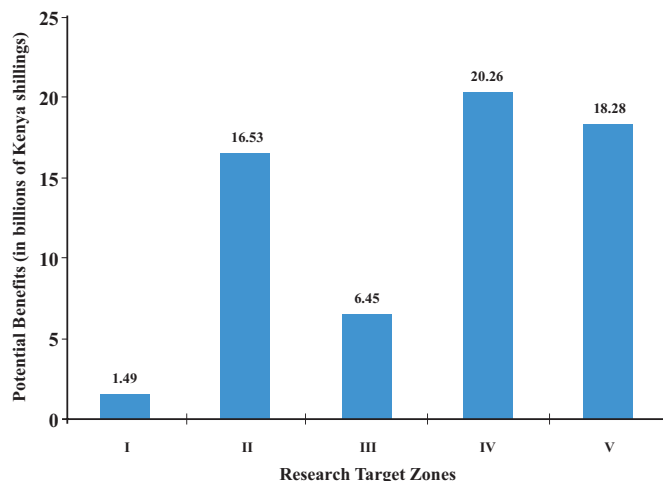
Zone I: Coastal areas
Zone II: Arid and semi-arid areas with relatively low population density
Zone III: Arid and semi-arid areas with relatively high population density
Zone IV: Medium rainfall areas with high population density
Zone V: High rainfall areas with both high and low population densities

Figure 2. Distribution of Potential Benefits to SFPNRP Research Target Zones

be small compared to the potential returns from investment in "inorganic fertilizer management" and "soil organic matter management," but it is over 50% of the returns from KARI's entire wheat research program, and more than 2/3 of returns from research on cassava.

The distribution of research gains is depicted in figure 2. Zones IV, V, and II captured the most benefits—20, 18, and 16 billion shillings, respec- tively—but for very different reasons. Zones IV and V cover relatively high-potential agricultural lands, and the considerable benefits accruing to these zones (32% and 29%, respectively) stem from the large number of high-value commodities whose yields might be significantly raised by improved soil fertility management. In contrast, zone II has relatively fewer production systems and, save for livestock, its commodities are of lower market value. This zone's relatively large gains (26%) are due instead to its great expanse and large livestock population. Zones I and III registered the most modest gains; in zone I, estimated commodity net yield gains were low, while zone III—the "hilly masses"—is small in area.

Conclusions

A fundamental assumption driving the evaluation procedure—one that is very clearly reflected in the results—was that the impact of research innovation in soil fertility management depends on, and is discernible from, yield gains across several commodities produced in highly-integrated farming systems. The results also highlight the fact that gains from research on soil fertility management are bounded by the genetic potential of the crop and livestock varieties available to farmers. This has a number of important implications for research management and policy.

First, the results suggest that growing efforts to integrate "traditional" applied commodity-focused research (e.g., breeding for useful traits) with farming-systems-oriented adaptive-research initiatives are well-founded. But in research organizations like KARI, applied and adaptive research activities are often housed in distinct and historically independent administrative units. Applied research programs like the SFPNRP typically have wide, often national, geographic mandates. In many cases, they have limited field presence and therefore little experience in adaptive work. If the potential gains suggested by the analysis are to be realized, management structures, and processes that support cross-program planning and implementation of research must be designed and, more importantly, institutionalized.

Second, because the results indicate that the greatest potential returns (61%) fall within high-rainfall areas (zones IV and V), recent initiatives by KARI and its partners to "recapitalize" soils in these areas appear to be justified. However, even as poverty and declining yields linked to soil nutrient depletion deepen in these high-rainfall areas, similar processes are occurring much more rapidly in Kenya's low-rainfall areas. It is therefore noteworthy that a significant share (almost 37%) of the potential benefits fall within drier areas (zones II and III). Because of continued migration from high- to low-rainfall areas, the efforts to overcome constraints on improved soil fertility management in drier areas do not only pass the efficiency test, they also brighten the prospects for improving rural equity (by blunting the growth of poverty in these zones) and stemming land degradation. Moreover, as population density in drier areas increases, the potential positive effects on rural income distribution and natural resource conservation are likely to increase in importance.

The purposely-simplified evaluation method described here provides insight into the potential impact of research on soil fertility management in Kenya. Indeed, yield-based evaluation can give reaonable first approximations of the benefits of NRM research. However, while such an evaluation may be useful in forecasting yield-based benefits, it remains insufficient; it does not address the important non-yield effects of research on soil fertility management. For example, research to reduce runoff and increase infiltration has important potential benefits for downstream communities, in the form of reduced flooding and erosion. The model must therefore be extended if it is to account for the differential effects on welfare that result from such research.

About this study…

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Full details of this procedure are reported in two KARI documents: *Soil Fertility and Plant Nutrition Research Priorities in Kenya: Main Report of the Priority Setting Working Group* (Nairobi: Kenya Agricultural Research Institute, 1998); and *Soil Fertility and Plant Nutrition Research Priorities in Kenya: Technical Annex to the Main Report of the Priority Setting Working Group* (Nairobi: Kenya Agricultural Research Institute, 1998).

Additional information is contained in chapter 10 of *Agricultural Research Priority Setting: Information Investments for Improved Use of Resources,* ed. Bradford Mills (The Hague: ISNAR, 1998). An application of the procedure in a commodity research program is described in *Commodity Program Priority Setting: The Experience of the Kenya Agricultural Research Institute*, by M. W. Kamau, D. W. Kilambya, and B. Mills (ISNAR Briefing Paper No. 34, May 1997).